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14. ABSTRACT
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Report Title

Final Report: Velocity Measurement Systems for a Low-speed Wind Tunnel

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u> <u>Paper</u>

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

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TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Because of the issue of space in our laboratory and having to wait until the end of the semester for a room to become available for conversion to a wind tunnel laboratory, the PIV and hotwire equipment has not been used as of yet, and so no scientific progress or accomplishment can be reported. This work will take place in the summer of 2015 and the complete facility and equipment will be operational by the end of the summer.

Technology Transfer

N/A

Department of Defense
Research and Education Program for HBCU/MI – Equipment/Instrumentation, FY 2013
BAA W911NF-13-R-0008

Velocity Measurement Systems for a Low-Speed Wind Tunnel
Grant W911NF-14-1-0031, Final Report

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Abstract

Funds were provided by the Army Research Office for the purchase of TSI hot-wire anemometer equipment and a Dantec particle-image velocimetry system, along with a small amount for facilities modification, for use in boundary-layer control studies and in fluid mechanics instruction. All equipment for which funds were provided has been purchased. To use the PIV system, which requires the use of a seed generator, the wind tunnel at TAMU-CC must be converted into a closed-circuit facility. Plans for the modification have been completed, and the final work is awaiting the availability of a classroom at the end of the current semester which will be converted into a wind-tunnel laboratory. The re-location of the wind tunnel to this laboratory will allow users to secure the laboratory equipment and to operate the wind tunnel without disrupting other functions in the facilities.

1. Introduction

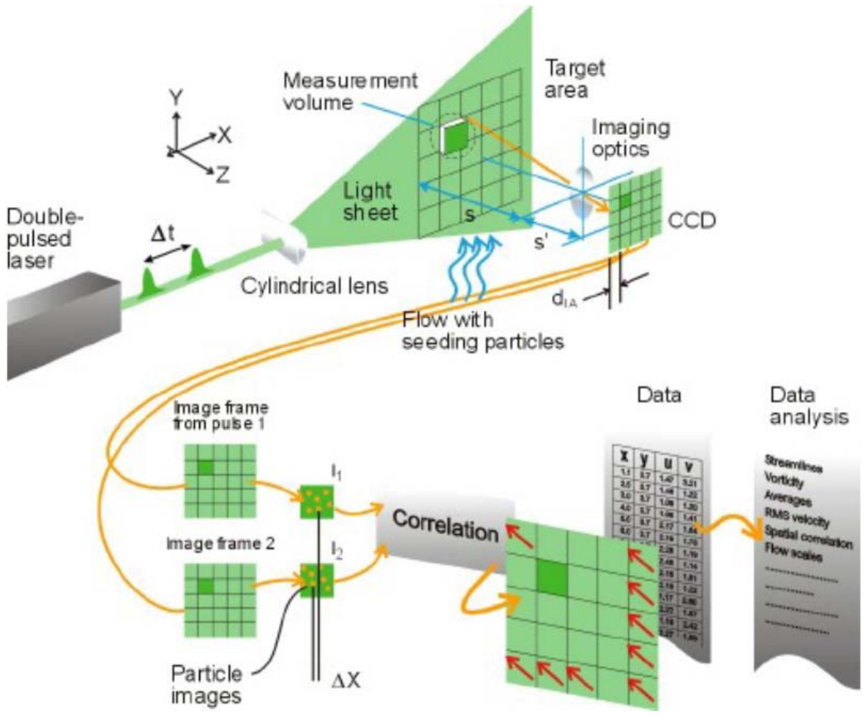
The School of Engineering and Computing Sciences at Texas A&M University – Corpus Christi (TAMU-CC) applied for funds under the DoD Research and Education Program for HBCU/MI – Equipment/Instrumentation to purchase velocity measurement equipment for a low-speed wind tunnel currently being used by the Mechanical Engineering program at TAMU-CC. This equipment consists of a two-component digital particle-image-velocimetry (PIV) system manufactured by Dantec Dynamics and a hot-wire anemometry system and components manufactured by TSI, Inc.. This equipment will be used to conduct wind-tunnel research on airfoils at low Reynolds number and will also be used in the teaching of fluid mechanics and experimental methods to undergraduate students at TAMU-CC. Texas A&M University – Corpus Christi is a Primarily Undergraduate Institution (PUI), Hispanic-Serving Institution (HSI) situated in south Texas, where 82% of the south Texas population is from underrepresented groups, and TAMU-CC enrollment comprises 46% underrepresented minority students.

2. Equipment / instrumentation acquired and impact on research and STEM

The School of Engineering and Computing Sciences at TAMU-CC owns a Hampden H-6910-12-150-CDL wind tunnel, which will be described in more detail below. This wind tunnel was acquired by the School around the time the mechanical engineering degree program was established a few years ago, but no velocity measurement instrumentation was acquired with it. Therefore, the equipment for which funds were requested consisted of two separate, state-of-the-art velocity measurement systems, a digital particle-image-velocimetry (PIV) system and a hot-wire anemometry system. Both of these systems have been acquired.

Digital Particle-Image Velocimetry System

The digital PIV system is manufactured by Dantec Dynamics. This system consists of a laser that can be "fired" accurately over small time intervals (see accompanying figure). The laser light illuminates a sheet cutting through the flow field of interest, which is seeded with small particles. Two pulses of the laser in rapid succession create a pair of images that are each collected by optics arranged perpendicular to the laser sheet and processed by an analyzer and software. The software essentially tracks the particles in the field illuminated by the laser sheets and thus measures the motion of each particle. The software determines the distance each particle moves between the laser bursts. If the distance moved by each particle and the time separation between the laser bursts are known, the software can compute the local velocity vector at each point in the flow, as well as other statistics related to the velocity field, such as magnitudes of velocity fluctuations and mean velocity gradients. The Dantec system under consideration has the ability to produce time-resolved measurements of the flow, in addition to time-averaged velocity fields, so that instantaneous maps of the velocity field and its statistics may be generated.



The PIV system acquired from Dantec consists of two major subsystems. The first consists of the laser and the optics necessary to generate the light sheets. The specific Dantec components are as follows (Dantec part numbers listed):

9138A7511 DualPower 15-1000 Laser 2 x 15 mJ at 1000 Hz 527 nm
9080X0901 Light Sheet Base Module
9080X8971 Entrance Module P9.4 mm
9080X0941 Angle Module 1
9080X0951 Angle Module 2
9080X0911 Variable Focus Module

The DualPower laser operates at a wavelength of 527 nm and can deliver 15 mJ of energy per pulse (two pulses per cycle of data acquisition) at that wavelength. The duration of each pulse is on the order of 150 nanoseconds. The various modules are used to create the laser light sheet from the laser pulses.

The second subsystem consists of the image-gathering optics and high-speed digital camera and the software to analyze the images, along with a computer that controls the PIV system and performs the data analysis. The specific Dantec components are as follows (again with Dantec part numbers listed):

9084C2121 SpeedSense M110 Camera 1 MP 1630 fps, 3GB
9080C2211 High Performance Filter for 527 nm and 532 nm
9084C1021 Zeiss lens kit Zeiss 50 mm f/1.4 lens
9080N0771 Timer Box, incl. Timer Card Cable Box and 4x10m BNC
9080S0571 DynamicStudio Base Package
9080S0581 2D PIV Add-on for DynamicStudio
PC-B 2 Quad Core CPU, 6 GB RAM, 2 X 1 TB HDs, Win 7 64 OS

The camera is a high-resolution, high-speed digital camera with a 1 megapixel image and a frame rate of 1630 frames per second, allowing for high spatial and temporal resolution. The filter and lens kit accompany the camera, and the timer box provides for synchronization between laser pulses and shutter openings. The DynamicStudio software package, which will be installed on the computer listed in the Dantec system, includes the following features:

- Graphical devices wiring and synchronization interface with wizards to guide the user through the synchronization steps
- On-line device setting capability for on-line adjustments (e.g. 'time between pulses, Δt' with PIV measurements)
- Automatic device detection
- Camera support
- Cyclic phenomena
- Image stitching
- Image processing library
- Advanced graphics
- Proper orthogonal decomposition (POD) with corresponding Matlab link

The 2D PIV Add-on software for DynamicStudio adds the following capabilities:

- Image processing: Image balance, arithmetic (mean, min/max), re-sampling, stitching
- Image conversion: resolution, double frames, single frames, reverse frames
- Masking: Mask definition, image and post process masking
- PIV signal processing: auto correlation, cross correlation, adaptive correlation (multi-pass), average correlation, least squares matching (LSM), adaptive PIV (method iteratively optimizes the size and shape of each interrogation area in order to adapt to local flow gradients and seeding densities)

- Vectors and derivatives: POD snapshot, POD projection, streamlines, vector arithmetic, vector statistics, vector/scalar subtraction, scalar derivatives (velocity gradients, 2-D vorticity, 2-D Jacobian, divergence)
- Plots: time line extraction, profile plot, spectrum, scalar maps (*U* and *V* velocities, velocity magnitudes)
- Coordinates: grid interpolation, vector dewarping, vector interpolation, vector re-sampling, vector rotation/mirroring, vector stitching
- Statistics: subpixel analysis, vector statistics

Additional equipment that will be needed to operate the system includes two particle generators and fog liquid:

9010F0031 Liquid Seeder, High Volume 3 Bar Back Pressure
91S00 Dantec 1500 Particle generator
UST50 Fog Fluid Standard, 4 liter

The liquid seeder provides the most effective operation of the PIV system. However, it requires a closed-circuit wind tunnel for safe operation. The other generator creates a non-toxic "smoke" that does not require a closed-circuit facility, just reasonable ventilation.

TSI Hot-wire Anemometry System

The hot-wire anemometry system is manufactured by TSI, Inc.. The hot-wire anemometer has been in existence for a long time, but it still remains one of the best devices for obtaining information about unsteady flows at a single point because of its high frequency response. A hot-wire anemometer is simply a very thin wire usually supported by two prongs. A current is passed through the wire, heating it. As flow moves past the wire, heat is transferred away from the wire, and so its resistance changes. This change in resistance can be detected by various means. One typical method is to add circuitry that will maintain a constant current by changing the voltage being supplied to the wire. Another is by maintaining a constant temperature, also by changing the wire voltage. In either case, it is possible to construct a calibration curve between the velocity of the flow past the wire and the voltage necessary to maintain either constant current or constant temperature, so that a voltage measurement will produce the corresponding flow velocity. Because of the typically high frequency response of hot wires, they are especially useful for measuring fluctuating velocities at a single point and for determining the frequency content of oscillating flows.

The TSI hot-wire anemometer system acquired is the TSI IFA 300 constant-temperature anemometer (CTA) system. The basic IFA system consists of the following components:

- IFA300 Cabinet with SMARTTUNE Constant Temperature Anemometer (CTA) Module with Signal Conditioner
- (1) 5m Probe Cable
- (3) 2m Output Cables
- Thermocouple and Extension Wire
- Shorting Probe Kit For Single and Dual-Sensor Probe Supports

- ThermalPro Software For Calibration, Data Acquisition and Analysis

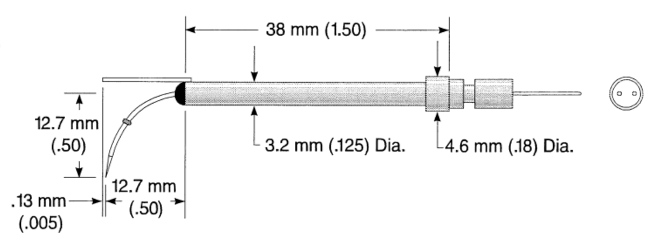
The TSI 183150 Add-On Channel package for the IFA 300 includes the following components:

- SMARTTUNE Constant Temperature Anemometer (CTA) Module with Signal Conditioner, Probe Cable and Output Cable (this CTA Module is pre-installed when ordered together with IFA300 System or Auxiliary Cabinet)

The IFA 300 features ultrahigh frequency response and low-noise circuits. The SMARTTUNE bridge optimization technology eliminates tuning, whether performed manually or by a computer mouse. The IFA 300 system includes a thermocouple probe for use in temperature measurements. The shorting probe kit is used to measure the resistance of the anemometer wire, an important quantity in probe calibration. The add-on package allows for the measurement of a second velocity component. The ThermalPro software offers complete experiment documentation, automated calibration, traverse control, and data acquisition and analysis for up to sixteen anemometer channels. Complete sensor calibration and detailed analysis and display of two-sensor data are also features of this package.

The following sensors (the actual "hot-wire" probes of the hot-wire system) were chosen, along with the corresponding supports:

1212-20 Probe, Sensor Upstream, -20 Film (2)
1218-20 Probe, Boundary Layer, -20 Film (1)
1245-20 Probe, Crossflow X, -20 Film (2)
1150-18 Probe Support, Single Sensor, 18" Long
1155-18 Probe Support, 2 Sensors, 18" Long



The first probe is a standard single-wire probe that measures one velocity component. It is primarily useful in measuring wake velocities behind a blunt object. The second probe is a boundary-layer probe. This probe model is illustrated to the right. It allows for measurements close to walls while protecting the sensing element (at the bottom of the figure). The "Crossflow X" probe is a two-wire probe that allows for the measurement of two velocity components at once at the same location. The variety of probes will allow for the measurement of different types of velocity fields as the need arises. The probe supports are necessary for connecting the probes to the anemometer and for manipulating their positions.

Funds for additional components to complete the hot-wire system were requested, and the components were acquired. These components are as follows:

- ADCPCI-4 4-Channel PCI A/D Board with 12-bit resolution and 1MHz throughput, BNC-Connector Board and Cable

- 2-Axis Traverse with Dual-Axis Controller and a pair of dual-axis traverse stages, each with 600 mm travel, and articulated probe mount
- Air Velocity Automatic Calibration System with Pressure Regulator, Filtering System and 0-100 mmHg Differential Pressure Transducer

The ADCPCI-4 analog-to-digital conversion board will be used with the computer purchased with the PIV system and will be used by the ThermalPro software to acquire data from the hot-wire probe and to control the 2-axis traverse system, which will allow for precise, automated positioning of the hot-wire probe in the flow. The computer and ThermalPro software will also be used with the automatic calibration system. One of the drawbacks of hot-wire anemometer systems is the "drift" associated with the calibration curves, making the ability to calibrate the wires a necessity.

Impact on research and STEM

The School of Engineering and Computing Sciences at TAMU-CC has chosen unmanned vehicles as a research focus area, particularly unmanned aerial vehicles (UAVs) and remotely-operated vehicles (ROVs; typically underwater). Unmanned aerial vehicles tend to be smaller than conventional aircraft and in many cases fly more slowly. This means that the airfoils used in the construction of the UAV wings operate in the low Reynolds number regime, where many fluid mechanic issues affect airfoil performance (lift, drag) in ways different from airfoils operating at higher Reynolds numbers. The wind tunnel owned by the School (to be discussed further, below) offers an ideal environment in which to investigate the aerodynamics of airfoils at low Reynolds number. The PI on this proposal, David Bridges, comes from an experimental aerodynamics background and has experience in investigating the control of boundary layers on airfoils at low Reynolds number. Another faculty member at TAMU-CC, Dr. Magesh Thiyagarajan, is an expert in cold plasmas and has performed preliminary work on their use in controlling the boundary layer on an airfoil at low Reynolds number. Collaborative work is planned in this area. In particular, the ability to use plasma actuators to introduce naturally-amplified frequencies in the boundary layer to promote transition to turbulence, and thus prevent the formation of a laminar separation bubble at high angle of attack, will be studied. The instrumentation purchased with this grant will aid this research significantly, because it will allow for the direct measurement of the velocity fields to determine if the flow is attached under the control inputs, and for the measurement of the frequency content of the flow fields to determine the amplification of the frequencies introduced into the flow. More details concerning research with these systems are provided in Item 8, Use of instrumentation, below.

The overall mission of Texas A&M – Corpus Christi is to become one of the leading centers of higher education and research in the Gulf of Mexico region while serving the intellectual, cultural, social, environmental and economic needs of South Texas. The mechanical engineering program at TAMU-CC is a strong supporter of this mission. The PI is an associate professor of mechanical engineering at TAMU-CC and teaches courses in fluid mechanics and aerodynamics. The proposed instrumentation will enhance significantly the teaching of fluid mechanics to undergraduate students at TAMU-CC. An important topic covered in fluid mechanics is the control volume method for determine forces exerted by fluids on objects. This method often requires the integration of velocity fields, including wakes behind objects. The PIV system will allow the measurements of the wakes of objects such as circular cylinders and the integration of those wake velocities to determine the drag of those objects. The students will thus see a direct physical application of a concept taught in class. Further, the inherently unsteady nature of such flows, in particular flows associated with vortex shedding, is discussed in class, and the PIV and hot-wire systems will provide real-life examples of data from such unsteady, oscillating flows. Additionally, the acquisition of these two systems will enhance the instruction in experimental methods in our program. Students will be exposed to and learn how to operate state-of-the-art fluid dynamic instrumentation systems. The mechanical engineering program at TAMU-CC is an undergraduate program only, and typically faculty with research projects will use undergraduate students in their research programs. Research projects using this equipment will involve undergraduate students.

The mechanical engineering program at TAMU-CC is relatively young, but from almost its beginning it has been involved in STEM outreach efforts. Summer camps for high school students have been conducted since 2010 to introduce students to various aspects of engineering. In 2010, middle school and high school teachers were trained to educate students about careers in engineering, engineering technology and the nuclear power industry. The curriculum included both lecture and lab sessions in electrical and digital systems. Additionally, field trips to a nearby nuclear power plant and an oil refining facility were organized to introduce teachers to the industry. Later, outreach events such as the Coastal Bend Engineering Competition and the Engineering Design Fair were implemented. In the summer of 2011, the focus of the summer camp was on wind turbines, and for the last two summers, the STEM outreach camp has studied the design and use of remotely-operated underwater vehicles. Another workshop to help prepare secondary school teachers for STEM subjects is currently in the planning stages. An attempt will be made to incorporate an experiment involving the PIV and hot-wire systems in this workshop and in future STEM summer camps. The PIV system will be particularly useful in this endeavor, in that it provides quantitative information in a graphical format that allows for visualization of the flow through the measurements of the vector velocity field.

3. Departments and institutions using equipment

Currently, the mechanical engineering (MEEN) program at TAMU-CC is housed in the School of Engineering and Computer Sciences, along with the Mechanical Engineering Technology (MET) and Electrical Engineering Technology (EET) programs. These are the only engineering programs on campus at the present, and all three are undergraduate programs only. It is primarily faculty in the fluids/thermal sciences area in MEEN/MET that will use this equipment for research, and students in the fluid mechanics classes in the MEEN and MET programs that will benefit from instructional use of the equipment, as well as students in the summer STEM camps and STEM teachers in workshops. Because of the relatively young age of the engineering programs at TAMU-CC (four years for the MEEN degree program), few research collaborations have been established with other institutions, although this is expected to change as TAMU-CC's involvement in the Texas Engineering Experiment Station (TEES) system expands.

4. Interface with existing resources / upgrades to existing facilities

As discussed earlier, the School of Engineering and Computing Sciences owns a Hampden H-6910-12-150-CDL open-circuit, low-speed wind tunnel. The maximum speed of the tunnel is approximately 150 ft/s, and its test section measures 1 ft by 1 ft perpendicular to the flow direction and is approximately 2 ft long. The sides of the test section are Plexiglas, making it ideal for PIV measurement systems. Normally the small size might pose a disadvantage. However, as one of the primary goals of the research to be conducted in this facility is low Reynolds number aerodynamics, the small size will not be an inhibiting factor. The ease of access resulting from its dimensions will enhance both the research and the educational activities to be conducted in the wind tunnel. The velocity measurement instrumentation acquired with this grant will upgrade this wind tunnel to a research-grade facility.

5. Estimated useful life of instrumentation and maintenance plans

Both the PIV and the hot-wire anemometer systems essentially have no moving parts and thus have expected long lives with little maintenance. The primary component that would have to be replaced in the PIV system is the laser, and a Dantec representative has stated that such a laser used by Dantec has operated for seven years with no decrease in performance. The hot wire sensing probes can break in use (a fairly typical occurrence), and so the School will replace these as necessary. Basic maintenance on the traverse system and any other "moving parts" will be performed by the laboratory staff in the School. Funds for the upkeep of the systems and replacement of broken parts, which are expected to be minimal, will be provided by the School.

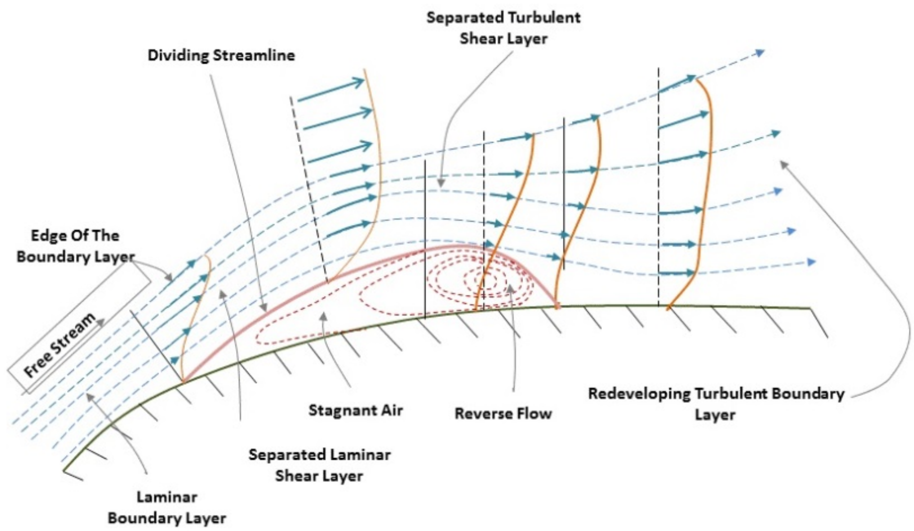
6. Training for optimal use of equipment

Because of the complexity of the PIV equipment, Dantec Dynamics will provide two days of on-site training on the installation and use of the PIV system. Their charge for the training is included in the budget. Because the training will be on-site and will be scheduled at an appropriate time (*i.e.*, during a break in classes when faculty are still on campus but do not have other commitments), there will be no charges for faculty time or travel associated with this training. The hot-wire system should require no training of TAMU-CC personnel by TSI; the experience of the PI in using hot-wire systems and the manuals provided with the system should be sufficient.

7. Use of instrumentation

As described before, these velocity measurement systems will be used in both research and instruction. These activities will be discussed in more detail here.

An airfoil with a relatively short chord and operating at relatively low speed, such as those typically found on UAVs, operate in the low Reynolds number regime. The Reynolds number is defined as the product of the speed and the characteristic length of the airfoil divided by the viscosity of the fluid. When the value of the Reynolds number is low, certain phenomena detrimental to the airfoil's performance take place that do not occur at higher values of the Reynolds number. Once such phenomenon is the laminar separation bubble (LSB; see image to right). An LSB is a short region of separated flow near the leading edge of the airfoil. The laminar flow over the airfoil encounters a region of increasing pressure past the pressure minimum, separates, transitions to turbulent flow, and reattaches to the surface of the airfoil. The results of the LSB are higher drag and reduced maximum lift coefficient, both negative contributions to airfoil and wing performance.



Numerous attempts to control the existence and extent of LSBs have been conducted (see the Bibliography for LSB control research by the PI). These have involved distributed suction, boundary layer transition trips, and other methods. The research currently under consideration will involve the use of plasma actuators to introduce low-energy disturbances into the flow. If the correct frequencies can be determined in advance, the introduction of disturbances at these frequencies will lead to natural transition of the boundary layer and thus reduce or eliminate the LSB. By using a plasma actuator, the frequencies can be varied and can be turned off when not needed, *e.g.* at low angles of attack, so that laminar flow (and thus lower skin friction drag) is maintained. A method for predicting the frequencies to be used is currently under development. In 1968, Wazzan, Okamura, and Smith, working in the research lab of the Douglas Aircraft Company, performed stability analyses for the Falkner-Skan boundary layer profiles and determined the neutral curves for the Falkner-Skan profiles at different values of the Falkner-Skan pressure-gradient parameter β. The idea behind the current research project is to use a "desktop" airfoil analysis program, XFLR5, to obtain the inviscid pressure distributions around different airfoil shapes. These will be used to determine the corresponding local values of the Falkner-Skan parameter β and will also be used in a simple implementation of Thwaites method to obtain the displacement thickness of the boundary layer on the airfoil. The local values of β and the displacement thickness will be used along with the results of Wazzan, Okamura, and Smith to determine the most unstable frequencies for the boundary layer at any given location at a given condition of Reynolds number and angle of attack. The experimental research will then be conducted by using the plasma actuator to introduce these frequencies into the boundary layer, with the goal of determining if the theoretical method does in fact predict the correct frequencies and if those frequencies do in fact lead to reduced LSB occurrence and improved airfoil performance. The hot-wire system will be used to assess accurately the frequency content of the flow, and the PIV system will be used to track the overall boundary layer behavior. These studies will be conducted in collaboration with Dr. Magesh Thiyagarajan, an assistant professor of mechanical engineering at TAMU-CC who is a noted authority on cold plasmas and who has conducted preliminary (unpublished) research at TAMU-CC on the effects of cold plasma actuators on airfoil performance at low Reynolds number. These research efforts will be conducted with student assistance, and as pointed out earlier, because of the absence of a graduate program in engineering at TAMU-CC, these student workers will be undergraduates.

With regards to instruction, the PIV system will provide an ideal method in the teaching of fluid mechanics for illustrating the control volume approach to determining forces on objects. The control volume method requires the integration of velocity fields across portions of the control volume's surface. This often involves the integrations of wake velocity profiles. The PIV system will be used to acquire instantaneous and time-averaged velocity profiles downstream of objects such as cylinders. These profiles will be provided to the students, who will use various forms of numerical integration to determine the drag of the object from the velocity data. Another fluid mechanic phenomenon that can be studied profitably by both the PIV and hot-wire systems is vortex shedding. Both systems will be used to determine the shedding frequencies associate with blunt objects such as cylinders which can then be compared to theory or previous experimental measurements. Additionally, the data provided by the PIV system will be used to estimate the fluctuating side forces on the objects.

Finally, an important component in the teaching of fluid mechanics is experimental methods, because much of our knowledge of fluid mechanics is based on experimental measurements. Further, the MET students are required to include laboratory experience in their fluid mechanics instruction. The PIV and hot-wire systems will provide the capability for instruction in state-of-the-art fluid velocity measurements.

Efforts in STEM education are a strong component of the undergraduate program at TAMU-CC. The School of Engineering and Computing Sciences has a strong STEM effort, including outreach to secondary school students, as well as with STEM teachers in the secondary school system. The PIV and hot-wire systems, as well as instruction in their use by the PI, will be made available to outreach efforts in the School to high school students involved in STEM efforts and to high school STEM teachers, as described above.

8. Current status

The wind tunnel described above is an open-circuit wind tunnel that resides in a large laboratory area at TAMU-CC. To operate properly, the PIV system requires that particles be generated and introduced into the flow. This can be done with a "fogger" that generates a non-toxic smoke, and this could be used safely in the lab area. However, the PIV system works more effectively with an oil-spray particle generator. These are typically used in closed-circuit wind tunnels and would not be appropriate for an open-circuit tunnel in an open lab. Initially, the plan was to use the fogger and vent the (non-toxic) fog to the outside of the building. However, it was determined that operating in that mode would place too large a burden on the HVAC system in the Engineering building. It was then decided to convert the wind tunnel into a closed-circuit facility, which would enable the use of the oil-spray generator, which would in turn produce better results. However, the conversion to a closed-circuit wind tunnel meant that the tunnel will take up more room, and so it will have to be moved into a different room than planned. Because of space issues in Engineering at the current time, the move had to be delayed until the end of the spring semester, so that a classroom currently in use can be converted into a wind tunnel laboratory. This will provide the ability to secure the wind tunnel and instrumentation, and will also reduce the disturbance to other people in the Engineering labs caused by the operation of the wind tunnel. The design of the return leg of the wind tunnel has been completed, and estimates for the construction work required to convert the wind tunnel and to outfit the new room have been received. The move and conversion of the wind tunnel will be done at the beginning of the summer, and the tunnel and instrumentation will be operational by the end of the summer.